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Optimal Placement and Sizing of Battery Energy Storage System in Renewable Energy System Integrated Distribution Systems

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Abstract

This research describes a technique for optimal allocation and sizing of a battery energy storage system (BESS) to palliate the power losses and voltage deviation index by integrating renewable energy sources (RES) in a Distribution Network. The optimum positioning and sizing of BESS in RES-linked distribution networks are acquired from a metaheuristic optimization algorithm dataset. With the help of the ETAP simulation platform, an inclusive analysis is conducted to analyze the results of BESS deployment. The ETAP software enables detailed modeling and simulation of BESS integration by taking into account factors like RES, load variations, and network constraints. Outcomes are demonstrated for the implementation of the recommended optimization method on the IEEE 33 and IEEE 34 bus distribution systems. Subsequently, outcomes came out with a significant decrease in the voltage deviances and power losses attained with the connection of RES and BESS components in the Distribution system. The results acquired contribute valuable help to the power system operators to work toward leveraging BESS for better performance and reliability

Categories: Renewable Energy Systems, Energy Efficiency and Conservation, Power Electronics and Renewable Energy
Keywords: renewable energy sources, battery energy storage system, distribution systems., voltage deviation index, power loss minimization

Introduction

As the world grows, the growth of population, pollution, urbanization, global warming, carbon emissions and other related issues are also evident. To counter this problem, various alternative methods are being used, one of which concerns ‘energy generation, storage, distribution’. The concepts of energy are growing worldwide as a result of evolving technological developments, decarbonization techniques, the formation of smart grids, and the speedy evolution in the usage of renewable energy sources (RES) [1].

The use of RES has enriched incredible reflection and has become a pleasing choice for scholars as a result of its hopeful features in reducing greenhouse gases [2]. However, the extensive collection of replacements and multifaceted performance conditions cause it to be tough to evaluate an energy storage system method for an accurate purpose. Many different resources are used to substitute conventional energy sources like wind, solar, tidal, and others. Battery energy storage system (BESS) is also a substitute energy resource that provides better efficiency and reliability.

Several qualities like lower maintenance, longer life span, non-exhaustive characteristics, and nature-friendliness are providing prominence to RES techniques. However, RES also brings some issues to the system [3].

By reason of the volatile energy creation from different RES, variability is proposed in the power grid. Maintaining the stability of the system can be very challenging as it can introduce fluctuations in voltage and frequency. This can also be the reason behind reliability issues and shortfalls in energy supply.

The implementation of reserve energy is an important consideration to oppose these challenges. This placement of alternate energy acts like a barrier, developing the grid’s capability to retort to abrupt variations. This also ensures a consistent power delivery. Various approaches like Energy Storage Systems (ESS), Flexible Generation Resources, and Demand Response Programs are consumed for the efficient implementation of alternate energy in smart grids [4].

BESS are considered over another method as they have higher adaptability and controllability. BESS also has a quick and stable response with geographical independence and environmental friendliness. This technology is essential to accelerate the replacement of non-renewable sources with non-conventional energy sources. Battery storage systems will perform a crucial role in the supply of green energy and replying to electricity demands [5]. Placement of BESS is a method that grants energy from renewables to be kept and then discharged when the energy is required most.

Battery energy storage method has a major role to play in guaranteeing houses and offices can be driven by green energy, even after the sun has stopped shining or the wind is not blowing. Each day, internationally, engineers at the National Grid and electricity grids must balance demand and balance. Handling these ups and downs becomes extra challenging to achieve a net zero carbon target. Conventional energy plants have conventionally been utilized to manage these ups and downs. However, BEES amenities can replace a part of these supposed higher power generators over time.

Smart battery software systems use a set of rules to synchronize energy generation and computerized control systems are utilized to choose when to store or discharge energy to the grid. The energy is discharged from the BESS during times of high demand, keeping budgets low and smooth-flowing electricity.

Integration of the BESS with the distribution network offers various benefits. These benefits comprise of low operational costs and reduction of active power loss. It can store and discharge energy, diminishing the loss of active power in the distribution network and increasing overall working capacity [6]. Furthermore, BESS also delivers quick response abilities and confirms reliable backing during sudden load increases.

Large tropical and subtropical areas receive adequate sunlight, and hence, solar energy is one of the most reliable sources of unconventional energy generation. Therefore, photovoltaics (PVs) are integrated along with BESS in the desired test systems. BESS combined with RES delivers various applications across different areas. These various applications influence the mutual proficiencies of BESS and RES to discourse different characteristics of the power system.

The foremost aims of this study are as follows:

(i). To perform a wide-ranging analysis of renewable PV integration in IEEE 33 and IEEE 34 bus systems by using E-Tap Software. It embraces network constrictions to exactly measure the accomplishment of the predicted allocation approach, and modeling of several features like load variations and RES.

(ii). Optimal placement of BESS in the IEEE 33 and IEEE 34 Bus distribution System in the PV integrated systems. This improves the complete functioning and consistency of the system [7].

(iii). In the IEEE 33 and IEEE 34 Test System by placing BESS at ideal positions, reduction of power losses is aimed. The main intention of this paper is to lessen transmission losses, improving the efficiency of power distribution all over the network.

(iv). The voltage profile enhancement is one of the major objectives of this study to scrutinize the influence of BESS placement on voltage regulation in diverse operating conditions by tactically integrating BESS into the network.

Previous research does not delve into the deep analysis of IEEE 34 test systems. Although several works discuss the usage and benefits of RESs and BESS separately, there is also a lack of studies on the integrated application of RESs and BESS in test systems.

Battery Energy Storage Systems (BESS)

The main aim of implementing BESS on the power system is to obtain higher productivity. It helps to obtain better voltage profiles, reduction in voltage deviation, and decrease power losses. BESS also gives congestion relief and resolves the issue of network expansion deferral. Improvements in reliability are observed by applying BESS.

Stocked up energy in the batteries through phases of excess or low necessity and discharging, when demand is at peak or when supplementary power is demanded is the major work of BESS. The principal apparatuses of a BESS comprise batteries, conversion systems, and control systems. Following is an outline of components used in BESS.

Electrochemical Battery Technologies

Numerous battery cells are linked in series or parallel in BESS. The electrochemical cells that are generally used in grid-connected systems are lithium-ion, lead-acid, sodium-sulfur batteries, and others. Electrochemical storage in a grid-connected system is portrayed in footings of reliability, efficiency, lifetime, and value, as illustrated and discussed.

The electrochemical properties of Li-ion batteries show high efficiency, i.e. up to 90%, though some marketable products offer a rated efficiency of up to 95%, high energy density, and a longer life span [8]. Regardless of being quite costly, this expertise is apt for applications that are grid-connected.

Power Electronics DC-AC Converter

With the help of converters, the construction of BESS with the AC distribution grid is designed. Inverters are applied to convert the direct current (DC) acquired from the batteries into the alternating current (AC). Other uses of converters are to balance voltage profiles and frequency between the electrical system and BESS. Therefore, it is worthwhile to design the power electronics-based converter to guarantee high efficacy and reliability [9]. Also, an auxiliary DC-DC converter can control the DC voltage by placing it in between the grid-connected DC-AC converter and the battery.

Battery Management System (BMS)

A BMS is characteristically an electronically regulated unit that controls and supervises the process of a battery throughout charge and discharge. Moreover, the BMS is accountable for linking with other electronically regulated and swapping the essential data about battery constraints. The voltage level, temperature, power intake, capacity, charging state and cycle, and other different parameters of the battery are measured and observed via the battery management system [10]. The usage of a BMS is normally intended for an optimal application of stocked energy in the battery cells. The BMS guards the battery cells from overcharging, which results from enormously quick charge and high discharge of batteries.

Energy Management System (EMS)

Energy management system (EMS) is a high-level podium made to control, monitor, and optimize energy use in an organization. It joins hardware and software parts to obtain, analyze, and act accordingly on energy data, permitting effectual resource management and cost savings.

The EMS delivers transmission operators with a superior perception of transmission and sub-transmission networks, along with the ability to function either as a fully integrated or standalone system with the advanced distribution management system. EMS allows the system to utilize better, by providing better load flow, optimal topology change, fault calculation, optimal power flow, contingency analysis, performance indices, and voltage stability.

Safety Systems

BESS will consist of safety equipment like fire extinguishers, smoke and cooling sensors, heating and cooling systems as per the system working and operating situations. A dedicated control and monitoring system will provide assurance of the harmless operation of the BESS and the prevention of treacherous incidents. The BESS will also be contained with CCTV monitoring and a secured constrained access area inside.

System performance evaluation

The effective working of the test system can be scrutinized only after the BESS installation. After the BESS installment in the system, detection of the voltage deviation and power losses takes place.

Voltage Deviation Index (VDI)

The variances between expected and actual voltage levels in a distribution system is defined as the voltage deviation index (VDI). On the grounds of impedance between the supplementary load and the substation, VDI is computed [11]. This can influence the voltage levels at various buses in the system.

To evaluate %VDI, Equations (1) and (2) are utilized. Where Equation (1) symbolizes the %VDI of the ith bus, and Equation (2) is the maximum %VDI of the network.

$$\%VDI_i = max_i^T(|v_ref - v_bi|/v_ref)100 \qquad (1)$$

$$\%VDI = \sum_{i=1}^{N} \%VDI_i \qquad (2)$$

To withstand a steady X/R fraction for constant process of the bus distribution system, a reduced VDI is essential.

Power Loss Minimization

Power loss minimization is the method of decreasing the amount of power loss in a distribution system though still meeting all parameters. It is vital in power distribution systems that go through more load variation compared to other systems [12].

Equation (3) denote the active power losses and Equation (4) represents reactive power losses, although Equation (5) indicates apparent power loss.

$$P_L = \sum_{s=1}^{M} P_L^1 \quad (3)$$

$$Q_L = \sum_{s=1}^{M} Q_L^1 \quad (4)$$

$$S_L = \sum_{s=1}^{M} S_L^1 \quad (5)$$

S describes the total branch count, and M signifies the number of branches. Equations (3), (4), and (5) are processed and compared either with or without BESS in the distribution systems.

Literature survey

The ideal positioning and sizing of BESS in the wind and solar RES-integrated IEEE 33 bus distribution systems for dipping power losses, minimizing VDI, and improving overall system reliability are performed by Barla, Mohan Chaitanya, and Dipu Sarkar et al [7]. Yuvaraj et al. did their research on the optimal placement of the DG and DSTATCOM in a radial IEEE 34 bus test system utilizing an optimization process [13]. The line impedance data and load data for the IEEE 34 bus test system are taken from the research by Chis et al., worked on capacitor allocation in distribution systems using heuristic approaches [14]. The study by Balu and Mukherjee propounds a meta-heuristic optimization process to acquire the optimum positioning and sizing of the distributed generation in a radial bus test system. A multi-measures approach is used to optimize the weighting aspects involved [15]. For designing of the IEEE systems, the line impedance data and load data are directly taken from the different research as mentioned in the literature survey, where the authors determined the desired value for data by using heuristic approaches. Originating of the required IEEE systems is not the aim of this study. Hence, heuristic techniques and algorithms used are not described in detail.

An assessment of equipment, optimization purposes, constraints, tactics, and remaining issues was clarified by Hannan et al. The ideal sizing of a working BESS is a dull task, which includes reasons such as maturing, value efficiency, optimum charging and discharging, carbon secretion, power undulations, unexpected load changes, and disruptions of transmission or distribution systems that need to be well-thought-out [16]. Therefore, the curiosity in raising a capable and consistent BESS is intensifying among researchers. Ankush et al. worked on BESS allocation in the IEEE 33 bus test system for boosted system implementation and improved voltage profile on E-tap simulation software [17].

RES can decrease carbon emissions and other air pollutants. They are self-replenishing. RES supports distribution energy systems that decrease power demand on the grid, reduce costs, and improve the reliability and security of serious infrastructure.

The optimal positioning, selection, and operation of BESS and RES were described by Valencia et al. [18]. Pompern et al. did a study on BESS in Distribution Networks Integrated with PV [19,20]. The practice of BESS sizing has been sorted in four parts, namely, the use of microgrids in BESS sizing, standalone hybrid RES, distributed RES, and RES power plants [21]. Nevertheless, the research did not contain BESS sizing techniques and optimization methods in detail. Further, energy storage systems in PV-integrated systems in view of lowest energy losses were intensely considered by Yang et al. [22]. Das did a study on BESS size recognition in RES [23]. Al Busaidi et al. gave an analysis of the optimum sizing of hybrid PV-Wind RES [24].

Electrochemical devices empower the measurement of an inclusive variety of ions, like hydrogen ions, heavy metals, electrolytes, and nutrients. Numerous types of BESSs such as vanadium redox, Li-ion, Ultra Battery, NaS, and lead-acid batteries are extensively used for stowing energy, and this was studied by Worku et al. [25]. Growing benefits in extreme PV dissemination distribution systems by use of battery energy stowing and capacitor positioning on the weight of swarm algorithm are described by Khaboot and Nathphol [26]. According to the research of Figgener et al., Li-ion batteries widely use electrical energy for storage in several countries like Germany [27]. Furthermore, as per Tsiropoulos et al. the value of Li-ion batteries has inclined to reduction because of the progress of their usage in electric vehicles [28]. The vital features of Li-ion batteries are their extreme energy per volume and capacity, speedy charge and discharge, and little self-discharge rate. As per the features of the Li-ion battery mentioned above, it needs less setting up area and has a quick reply to store or supply electrical energy. From self-discharging, it has a low energy loss rate. Thus, this research employed a Li-ion battery in the BESS. Some of the BESS technologies are more, mature and reliable, with further price reductions anticipated as described by Kempener [29].

Economic worries are still stopping BESS from getting to the height of becoming a conventional solution for additional services in the power grids as per Olatomiwa et al. [30]. An unsuitable forward approach for BESS can also head toward variability issues, fast deprivation, and uneconomical procedure of power grids by Jinqiang [31]. BESS planning and procedure are the solutions to an effective and well-organized key for grid ancillary backing. The analysis of multi-objective sizing of BESS for grid applications are done by Zheng et al. [32,33].

Ahmed et al. gave a detailed study of stacking the energy by battery storage, incomes in yet-to-come distribution networks [34]. The relevance of BESS for auxiliary services and the prevailing challenges were only pronounced from the sizing point of view. A review of hybrid-PV BESS was displayed in Rana et al. [35,36] to designate the means for generation upgrading, cost-dropping investigation, optimal sizing and control, power worth problems, and peak shaving. Though there is not any solo solution available to counter the climate crisis, energy storage offers a noteworthy opportunity to fast-track the evolution from a high-carbon to a low-carbon energy system and make a major universal impact.

Materials And Methods

BESS is incorporated into an IEEE distribution system by being shown as a controllable load or generation source within the power system simulation, permitting scholars to analyze its impact on grid stability, voltage regulation, and power flow by simulating its charging and discharging behavior across different scenarios.

Here, the simulating tool ETAP is used to adjust its charging and discharging power based on grid conditions and desired operational objectives. ETAP outperforms in simulating and analyzing power systems, principally for steady-state studies and transient studies. ETAP also offers an easily accessible interface and a wide-ranging suite of tools for designing of power, detailed analysis, and efficient operation, counting progressive features like security valuation. Thus, this study prefers ETAP over other simulating platforms.

In this research, the attention is on the IEEE 33 and IEEE 34 test systems whose specifications are shown in Table *1*. Here, the artificial intelligence (AI) tools are utilized for the verification of specifications.

IEEE System	IEEE 33	IEEE 34
Number of buses	33	34
Number of lines	32	33
Operating voltage	12.66 kV	11 kV

TABLE 1: IEEE Bus Distribution System

The methodology involves designing of the IEEE systems and allocating PVs at desired positions, followed by determining the ideal locations of BESS at which the best results are acquired.

The investigators attempt to identify ideal BESS positions to improve consistency, lessen voltage fluxes, and decrease power losses with the help of analyses and simulations. In this work, the PV arrays are placed in different locations taken from [7] as shown below. BESS is allocated in the system at different positions to decrease distribution system losses and control voltage deviation. The several cases considered here are shown in Table *2*.

Scenario	Cases	Location of PVs			Allocation of BESS
		Quantity	Bus Number	Capacity	
Scenario 1 IEEE 33 bus system	1(a)	3	5, 21, 31	400 kVA each	
	1(b)	3	5, 21, 31	400 kVA each	6, 7, 26
	2(a)	4	8, 21, 28 33	500 kVA each	
	2(b)	4	8, 21, 28, 33	500 kVA each	6, 7, 26
Scenario 2 IEEE 34 bus system	3(a)	3	5, 21, 31	400 kVA each	
	3(b)	3	5, 21, 31	400 kVA each	4, 8
	4(a)	4	8, 21, 28 33	500 kVA each	
	4(b)	4	8, 21, 28 33	500 kVA each	4, 8

TABLE 2: Various Cases Chosen for Two Different Scenarios

BESS, battery energy storage system; PV, photovoltaic

Table 2 provides for the quantity, locations, and specifications of PVs and positioning of BESS required in different scenarios to achieve the objective of this research.

Results

To study the efficacy of the anticipated procedure, two scenarios are carried out with different case studies. This part describes the results of optimally positioning the BESS in two different bus distribution systems specifically IEEE 33 and IEEE 34 bus distribution systems. ETAP software simulation is utilized and the acquired results are shown in the tables given below and depicted in the graphs presented below. There are a total of two scenarios, and four cases in each scenario are examined as shown in Table 2.

Scenario 1: Optimal allocation of PVs and BESS in IEEE 33 bus system

The optimal placement for BESS connected in the IEEE 33 bus distribution system as shown in Figure 1 is primarily attained in backing of two conditions i.e. lessening of power loss and decrease in voltage deviation. Four different cases are considered for a fair comparison of the proposed methodology. Tables 3 and 4 indicate the losses achieved and %VDI values of the IEEE 33 bus test system. It was witnessed that the value of power loss was higher i.e. 0.203 MW and 0.136 Mvar before installation of the RES and BESS in the base case.

Allocation of PV Array at Bus No. 5, 21, 31 in the IEEE 33 Bus Distribution System

Parameters	Base Case	PVs at Bus 5, 21, 31	
		PVs	PVs with BESS
Losses (MW)	0.203	0.148	0.111
Losses (Mvar)	0.136	0.102	0.078
Min. Voltage (kV)	91.309	92.227	93.447
%VDI	5.156	4.320	3.460

TABLE 3: Analysis of Results of Case 1(a) and 1(b)

BESS, battery energy storage system; PV, photovoltaic

Table 3 shows the losses, minimum voltage, and %VDI acquired in the base case and the cases integrated with PVs and BESS, where, PV array are placed at bus no. 5, 21, 31 in the IEEE 33 test system.

Allocation of PV Array at Bus No. 8, 21, 28, 33 in IEEE 33 Bus Distribution System

Parameters	Base Case	PVs at Bus 8, 21, 28, 33	
		PVs	PVs with BESS
Losses (MW)	0.203	0.107	0.090
Losses (Mvar)	0.136	0.072	0.063
Min. Voltage (kV)	91.309	93.647	94.825
%VDI	5.156	3.303	2.472

TABLE 4: Analysis of Results of Case 2(a) and Case 2(b)

BESS, battery energy storage system; PV, photovoltaic

Table 4 shows the losses, minimum voltage, and %VDI acquired in the base case and the cases integrated with PVs and BESS, where PV array are placed at bus no. 8, 21, 28, 33 in the IEEE 33 test system.

Scenario 2: optimal allocation of PVs and BESS in IEEE 34 bus system

The optimal placement for BESS set up in the IEEE 34 bus distribution system as shown in Figure 1 is primarily attained with the backing of two cases considered for a fair comparison of the proposed methodology. Tables 5 and 6 indicate the losses achieved and %VDI values of the IEEE 34 bus test system in three different cases. It was observed that the value of power loss was higher, i.e. 0.222 MW and 0.065 Mvar, before the installation of the RES and BESS in the base case, with conditions i.e. a drop in power loss and a decrease in the voltage deviation.

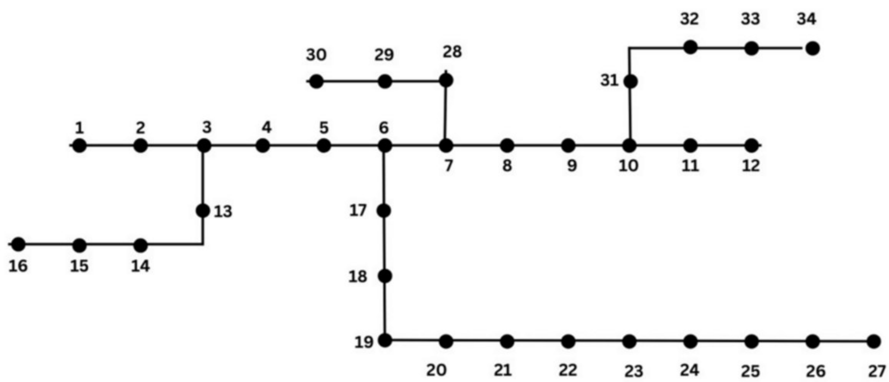

FIGURE 1: Single Line Diagram of IEEE 34 Bus System

Allocation of PV Array at Bus No. 5, 21, 31 in IEEE 34 Bus Distribution System

Parameters	Base Case	PVs at Bus 5, 21, 31	
		PVs	PVs with BESS
Losses (MW)	0.222	0.159	0.133
Losses (Mvar)	0.065	0.046	0.038
Min. Voltage (kV)	94.166	95.075	95.471
%VDI	3.426	2.749	2.355

TABLE 5: Analysis of Results of Case3(a) and Case 3(b)

BESS, battery energy storage system; PV, photovoltaic

Table 5 shows the losses, minimum voltage, and %VDI acquired in the base case and the cases integrated with PVs and BESS, where PV arrays are placed at bus no. 5, 21, 31 in the IEEE 34 test system.

Allocation of PV Array at Bus No. 8, 21, 28, 33 in IEEE 34 Bus Distribution System

Parameters	Base Case	PVs at Bus 8, 21, 28, 33	
		PVs	PVs with BESS
Losses (MW)	0.222	0.125	0.110
Losses (Mvar)	0.065	0.036	0.03
Min. Voltage (kV)	94.166	95.630	96.020
%VDI	3.426	2.191	1.804

TABLE 6: Analysis of Results of Case 4(a) and Case 4(b)

BESS, battery energy storage system; PV, photovoltaic

Table 6 shows the losses, minimum voltage, and %VDI acquired in the base case and the cases integrated with PVs and BESS, where PV arrays are placed at bus no. 8, 21, 28, 33 in the IEEE 34 test system.

Discussion

Scenario 1: optimal allocation of PVs and BESS in IEEE 33 Bus system

Allocation of PV Array at Bus No. 5, 21, 31 in the IEEE 33 Bus Distribution System

(i). Optimal allocation of BESS for the reduction in power loss

The benefits of power loss minimization also include increasing profit margins and help in avoiding fines and reimbursements.

In Case 1(a), the PV arrays of 400 kVA are placed on buses no. 5, 21, and 31 in the IEEE 33 system. Table 3 depicts the outputs acquired in this case. As shown in Figure 2, this results in minimized losses of 0.148 MW and 0.102 Mvar.

In Case 1(b), after the installment of BESS at bus no. 6, 7, and 26 in the same case, the losses are further reduced to 0.111 MW and 0.078 Mvar as depicted in Figure 2.

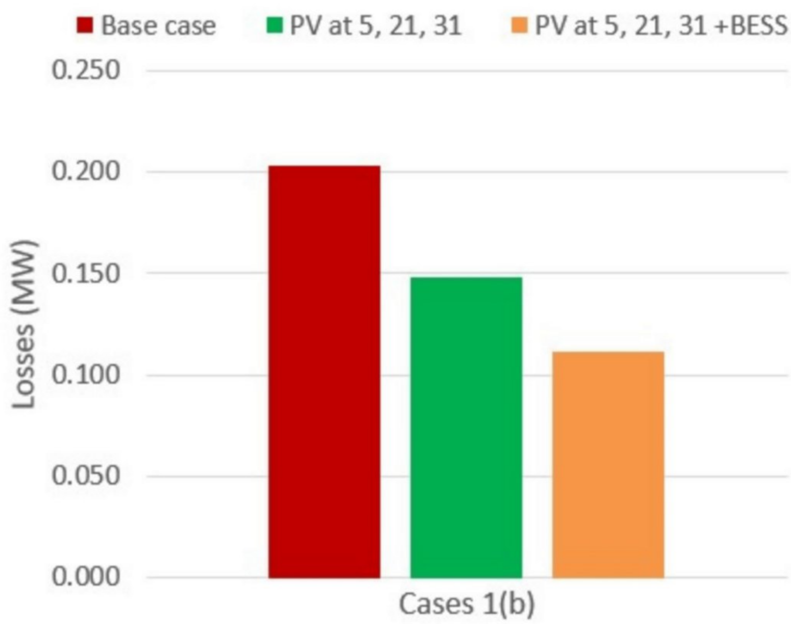

FIGURE 2: Comparison of Power Losses in Case 1(a) and Case 1(b)

(ii). Optimal allocation of BESS for the reduction in voltage deviation

Based on the impedance between the additional load and the substation, VDI is calculated. This can affect the voltage levels at different buses in the system.

In Case 1(a), the 400 kVA PV arrays are placed on buses no. 5, 21, and 31 in the IEEE 33 system. According to the outputs shown in Table 3, the value of %VDI also decreased from 5.156 to 4.320. The minimum voltage is achieved at 92.227 kV, which was 91.309 kV before the placement of PVs. This is depicted in Figure 3.

In Case 1(b), after the installment of BESS at bus no. 6, 7, and 26 in the same case, the value of %VDI in this case further decreased to 3.460. The minimum voltage after the BESS installation is achieved at 93.447 kV as shown in Figure 3.

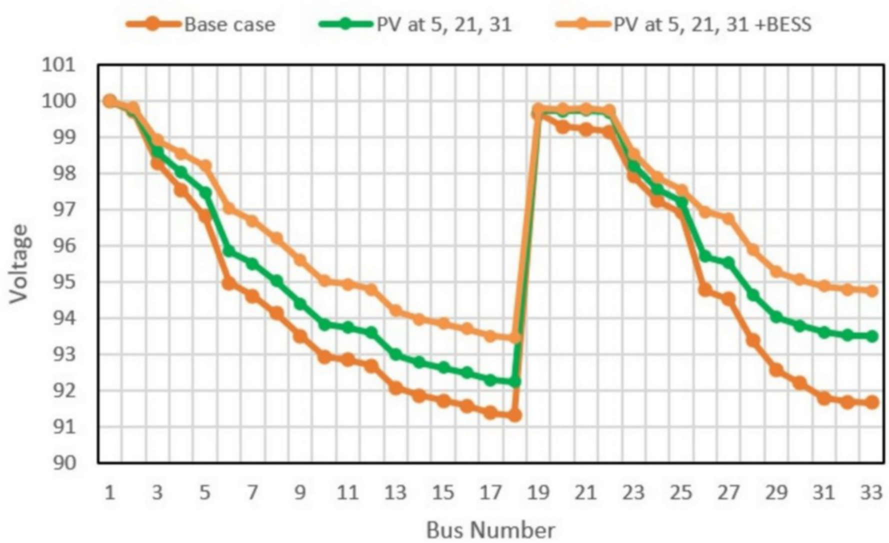

FIGURE 3: Voltage Profile of Case 1(a) and Case 1(b)

Allocation of PV Array at Bus No. 8, 21, 28, 33 in IEEE 33 Bus Distribution System

(i). Optimal allocation of BESS for the reduction in power loss

Minimizing power loss itself helps to enrich the voltage profile. Drop in power loss also helps to reduce harmful emissions.

In Case 2(a), the PV arrays of 500 kVA are placed on buses no. 8, 21, 28, and 33 in the IEEE 33 bus test system. Table *4* depicts the outputs acquired in this case. This results in minimized losses of 0.107 MW and 0.072 Mvar.

In Case 2(b), after the installment of BESS at bus no. 6, 7, and 26 in the same case, the losses are further reduced to 0.090 MW and 0.063 Mvar. Figure *4* depicts the attained results.

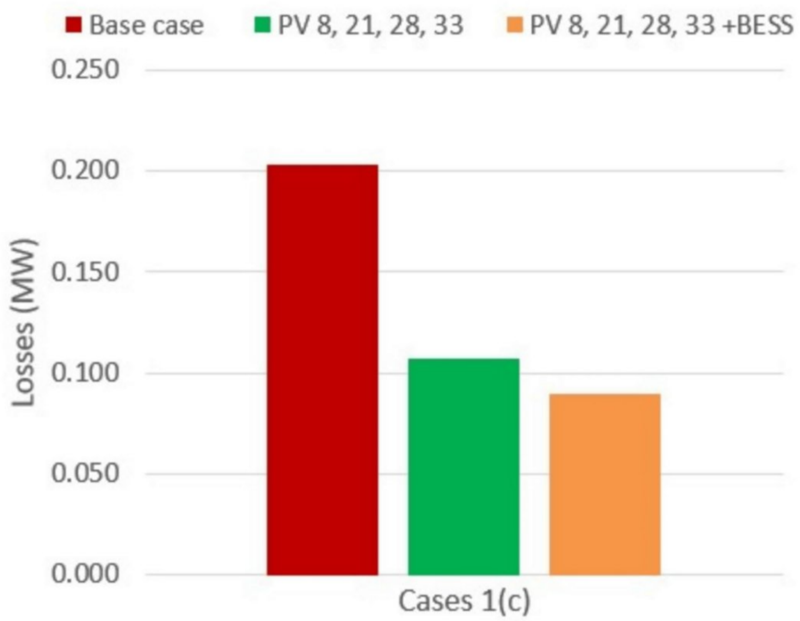

FIGURE 4: Comparison of Power Losses in Case 2(a) and Case 2(b)

(ii). Optimal allocation of BESS for the reduction in voltage deviation

In Case 2(a), the 500 kVA PV arrays are placed on buses no. 8, 21, 28, and 33 in the IEEE 33 system. According to the outputs shown in Table *4*, the value of %VDI also decreased from 5.156 to 3.303. The minimum voltage is achieved at 93.647 kV which was 91.309 kV before the placement of PVs as displayed in Figure *5*.

In Case 2(b), after the installment of BESS at bus no. 6, 7, and 26 in the same case, the value of %VDI in this case further decreased to 2.472. The minimum voltage after the BESS installation is achieved at 94.825 kV as shown in Figure *5*.

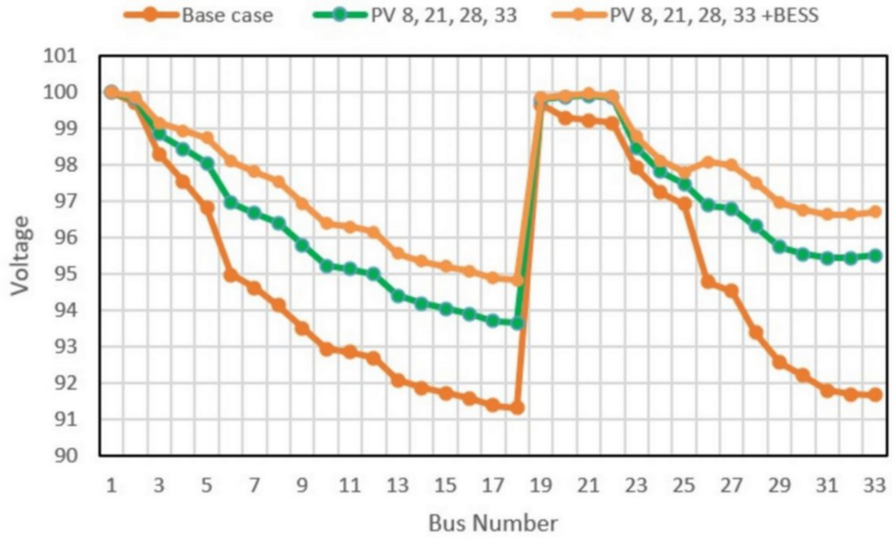

FIGURE 5: Voltage Profile of Case 2(a) and 2(b)

Scenario 2: optimal allocation of PVs and BESS in IEEE 34 Bus system

Allocation of PV Array at Bus No. 5, 21, 31 in IEEE 34 Bus Distribution System

(i). Optimal allocation of BESS for the reduction in power loss

In Case 3(a), the PV arrays of 400 kVA are placed on buses no. 5, 21, and 31 in the IEEE 34 system. Table 5 depicts the outputs acquired in this case. This results in minimized losses of 0.159 MW and 0.046 Mvar.

In Case 3(b), after the installment of BESS at bus no. 4 and 8 in the same case, the losses are further reduced to 0.133 MW and 0.038 Mvar.

Results of Case 3(a) and 3(b) are depicted in Figure 6.

These placements of PVs will also benefit in increasing profit margins and help in avoiding fines and reimbursements.

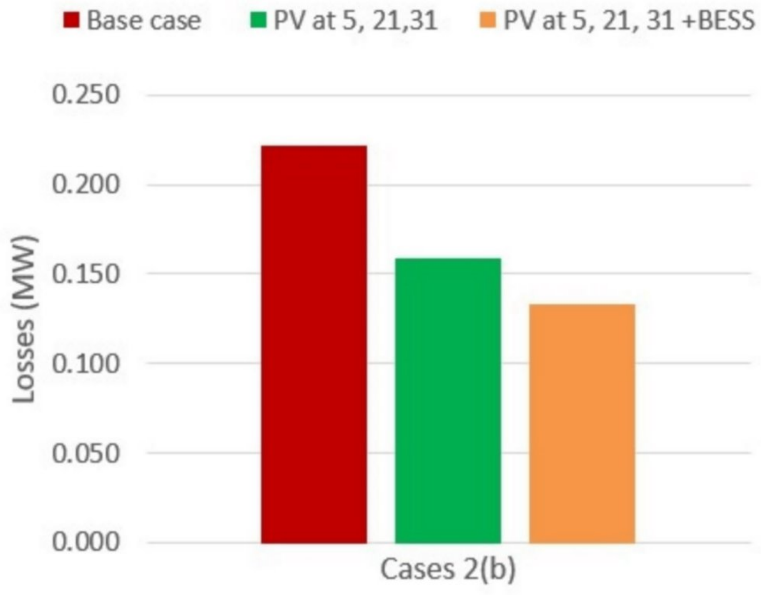

FIGURE 6: Comparison of Power Losses in Case 3(a) and Case 3(b)

(ii). Optimal allocation of BESS for the reduction in voltage deviation

In Case 3(a), the 400 kVA PV arrays are placed on buses no. 5, 21, and 31 in the IEEE 34 test system. According to the outputs shown in Table 5, the value of %VDI also decreased from 3.426 to 2.749. The minimum voltage is achieved at 95.075 kV which was 94.166 kV before the placement of PVs.

In Case 3(b), after the installment of BESS at bus no. 4 and 8 in the same case, the value of %VDI in this case further decreased to 2.355. The minimum voltage after the BESS installation is achieved at 95.471 kV.

These results are showcased in Figure 7.

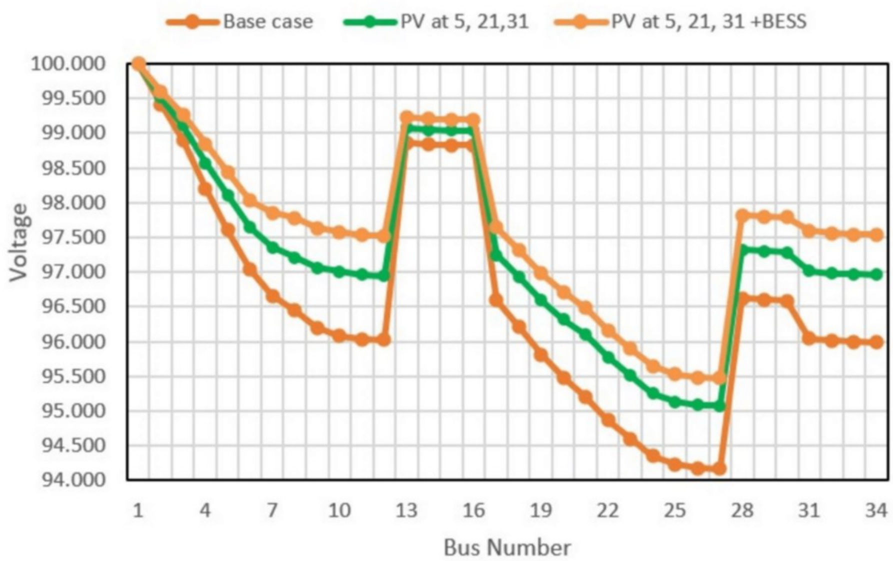

FIGURE 7: Voltage Profile of Case 3(a) and 3(b)

Allocation of PV Array at Bus No. 8, 21, 28, 33 in IEEE 34 Bus

Distribution System

(i). Optimal allocation of BESS for the reduction in power loss

In Case 4(a), the PV arrays of 500 kVA are placed on buses no. 8, 21, 28, and 33 in the IEEE 34 test system. Table 6 depicts the outputs acquired in this case. This results in minimized losses of 0.125 MW and 0.036 Mvar.

In Case 4(b), after the installment of BESS at bus no. 4 and 8 in the same case, the losses are further lessened to 0.110 MW and 0.03 Mvar. This is displayed in Figure 8.

With optimal placements of PVs, minimizing power loss itself aids in improving the voltage profile and helps to lessen harmful emissions.

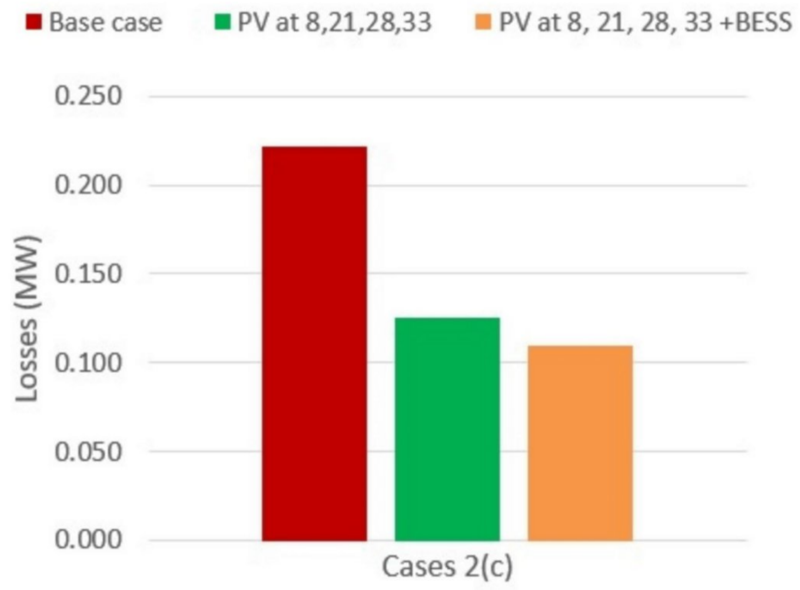

FIGURE 8: Comparison of Power Losses in Case 4(a) and Case 4(b)

(ii). Optimal allocation of BESS for the reduction in voltage deviation

In Case 4(a), the 500 kVA PV arrays are placed on buses no. 8, 21, 28, and 33 in the IEEE 34 test system. According to the outputs shown in Table 6, the value of %VDI also decreased from 3.426 to 2.191. The minimum voltage is achieved at 95.630 kV which was 94.166 kV before the placement of PVs.

In Case 4(b), after the installment of BESS at bus no. 4 and 8 in the same case, the value of %VDI in this case further decreased to 1.804. The minimum voltage after the BESS installation is achieved at 96.020 kV.

Figure 9 represents this case as shown below.

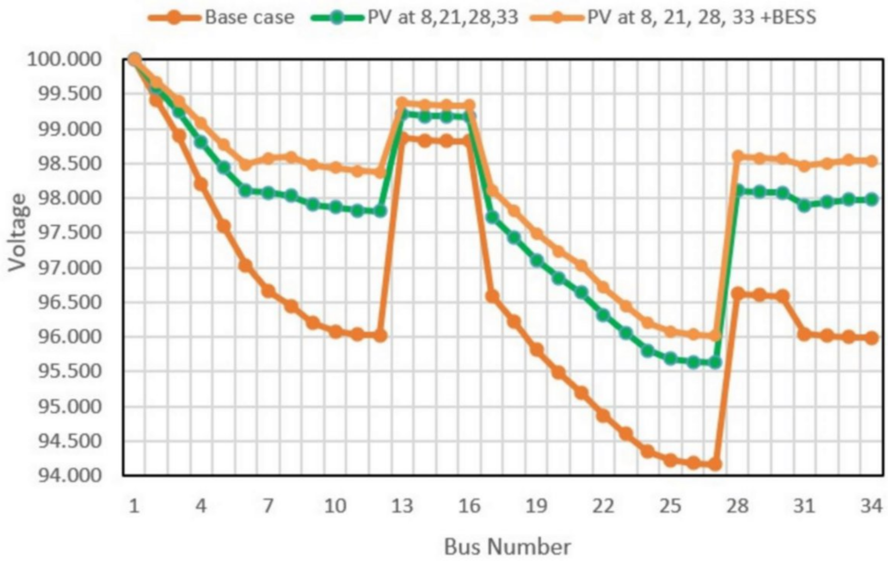

FIGURE 9: Voltage Profile of Case 4(a) and Case 4(b)

In all the cases within different scenarios, it is evident that the results acquired are much more efficient after the installation of PV RESs, which are further improved by installing BESS in the test system. This is very well described in the figures, where comparisons can be seen clearly.

Conclusions

The outcomes of optimally locating and sizing of BESS in RES-integrated bus distribution systems are systematically investigated in this study. This study delves into the requirements of unconventional sources of energy to resolve future issues of energy generation. The research is explained by minimizing power losses and VDI. Arithmetical equations illustrate the competence of the proposed methodology in obtaining the results by the BESS allocation with the RES-connected network. The IEEE 33 and IEEE 34 test systems are used up for the suggested technique.

The application of the ETAP software permitted for thorough and accurate modeling of the BESS integrated network. The end results acquired from the performed simulations unambiguously reveal the efficacy of the proposed approach. Remarkably, the methodology proved efficacious in minimizing power losses and VDI. The results acquired contribute valuable help to the power system operators to work toward leveraging BESS for better performance and reliability.

Appendices

We acknowledge the use of AI tools for copy editing assistance, including improvements to readability, style, and error correction in grammar, spelling, punctuation, and tone, with final responsibility for the content remaining with the authors.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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